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AËRIAL LOCOMOTION

WITH A FEW NOTES OF PROGRESS IN THE CONSTRUCTION OF AN AËRODROME

BY

ALEXANDER GRAHAM BELL
FORMERLY PRESIDENT OF THE NATIONAL GEOGRAPHIC SOCIETY

Reprinted from the NATIONAL GEOGRAPHIC MAGAZINE, JANUARY, 1907

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THE NATIONAL GEOGRAPHIC MAGAZINE

AËRIAL LOCOMOTION

With a Few Notes of Progress in the Construction of an Aërodrome*

BY ALEXANDER GRAHAM BELL

FORMERLY PRESIDENT OF THE NATIONAL GEOGRAPHIC SOCIETY

THE history of aërial locomotion is full of tragedies, and this is specially true where flying-machines are concerned. Men have gone up in balloons, and most of them have come down safely. Men have launched themselves into the air on wings, and most have met with disaster to life or limb. There have been centuries of effort to produce a machine that should fly like a bird, and carry a man whithersoever he willed through the air; and previously to 1783, the year sacred to the memory of the brothers Montgolfier, all experiments at aërial locomotion had this end exclusively in view.

Then came a period when the conquest of the air was sought through the agency of balloons. For more than one hundred years the efforts of experimenters were chiefly directed to the problem of rendering the balloon dirigible; and the earlier experiments with gliding machines, and artificial wings, and the projects of men to drive heavy bodies through the air by means of propellers were largely forgotten. The balloon was changed from its original spherical form to a shape better adapted for propulsion; and at last, through the efforts of Santos Dumont, we have arrived at the dirigible balloon of today. But in spite of the dirigibility of the modern balloon, it has so far been found impracticable to impart to this frail structure a velocity sufficient to enable it to make headway against anything but the mildest sort of wind. The character of the balloon problem has therefore changed. Velocity of propulsion rather than dirigibility is now the chief object of research.

THE BIRDS ARE ONCE MORE RECOGNIZED AS THE TRUE MODELS OF FLIGHT

It has long been recognized by a growing school of thinkers that an aërial vehicle, in order to cope with the wind, should be specifically heavier than the air through which it moves. This position is supported by the fact that all of Na-

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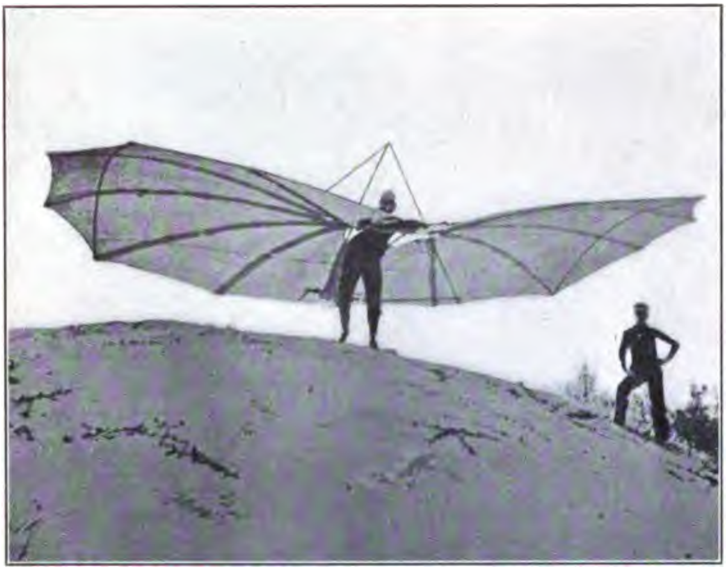
*An address read before the Washington Academy of Sciences, December 13, 1906, and specially revised by Dr Bell for publication in the NATIONAL GEOGRAPHIC MAGAZINE.



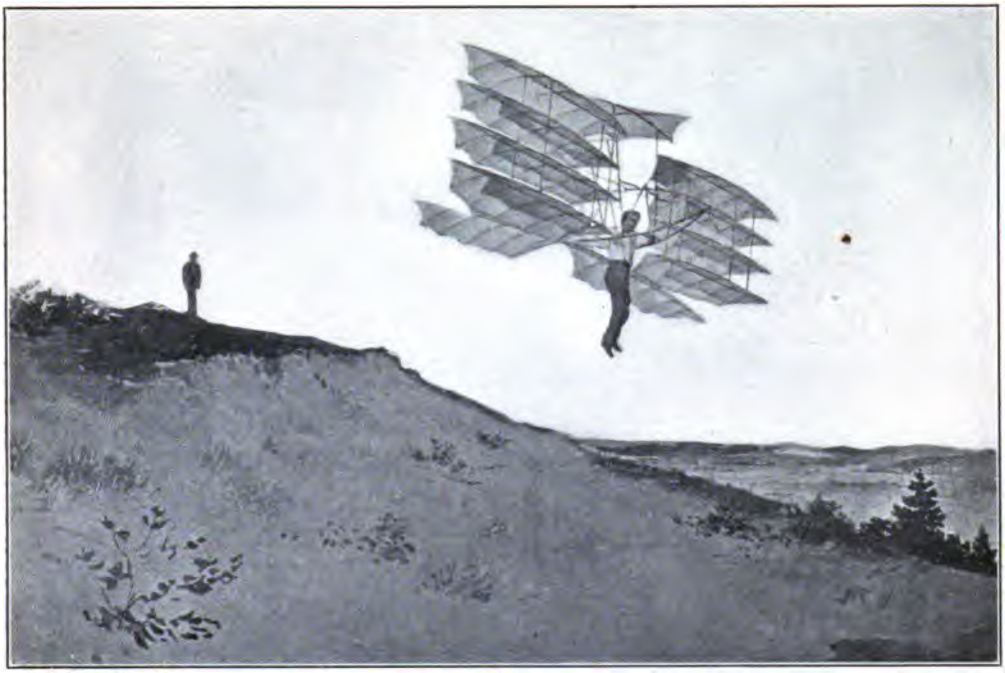
Lilienthal Gliding Machine as Reproduced in America for Chanute by Herring

ture's flying models, from the smallest insect to the largest bird, are specifically heavier than the air in which they fly, most of them many hundreds of times heavier, and that none of them adopt the balloon principle in flight. It is also significant in this connection that some of Santos Dumont's most celebrated exploits were accomplished with quite a small balloon, so ballasted as to sink in the air instead of rise. He was then enabled, under the influence of his motive power, to steer his balloon upward without the expenditure of ballast and to descend without the loss of gas. This probably typifies, for the balloon, the direction of change in the future. A reduction in the volume of gas coincidently with an increase in motive power will lead to greater velocity of propulsion, now the main desideratum. Then dependence upon velocity for support rather than gas may gradually lead to the elimination of the gas bag altogether; in which case the balloon will give birth to a flying machine of the heavier-than-air type.

However this may be, it is certainly the case that the tendency of aërial research is today reverting more and more to the old lines of investigation that were pursued for hundreds of years before the invention of the balloon diverted attention from the subject. The old devices have been reinvented; the old experiments have been tried once more. Again, the birds are recognized as the true models of flight, and again men have put on wings, but this time with more promise of success.

THE GLIDING FLIGHTS OF LILIENTHAL

Lilienthal boldly launched himself into the air in an apparatus of his own construction, having wings like a bird and a tail for a rudder. Without any motor, he ran down hill against the wind. Then, upon jumping into the air, he found himself supported by his apparatus, and glided down hill at an elevation of a few feet from the ground, landing safely at a considerable distance from his point of departure. This exhibition of gliding flight fairly startled the world, and henceforth the experiments of Lilienthal were conducted in the public eye. He made hundreds of successful flights with his gliding machine, varying its construction from time to time, and communicating to the world the results of his experiments with practical directions how to manage the machine under circumstances of difficulty; so that, when at last he met with the usual fate of his predecessors in this line, the experiments were not abandoned. They were continued in America by



Gliding Through the Air on Chanute's Multiple-winged Glider

Chanute of Chicago, Herring, and other Americans, including the Wright brothers, of Dayton, Ohio.

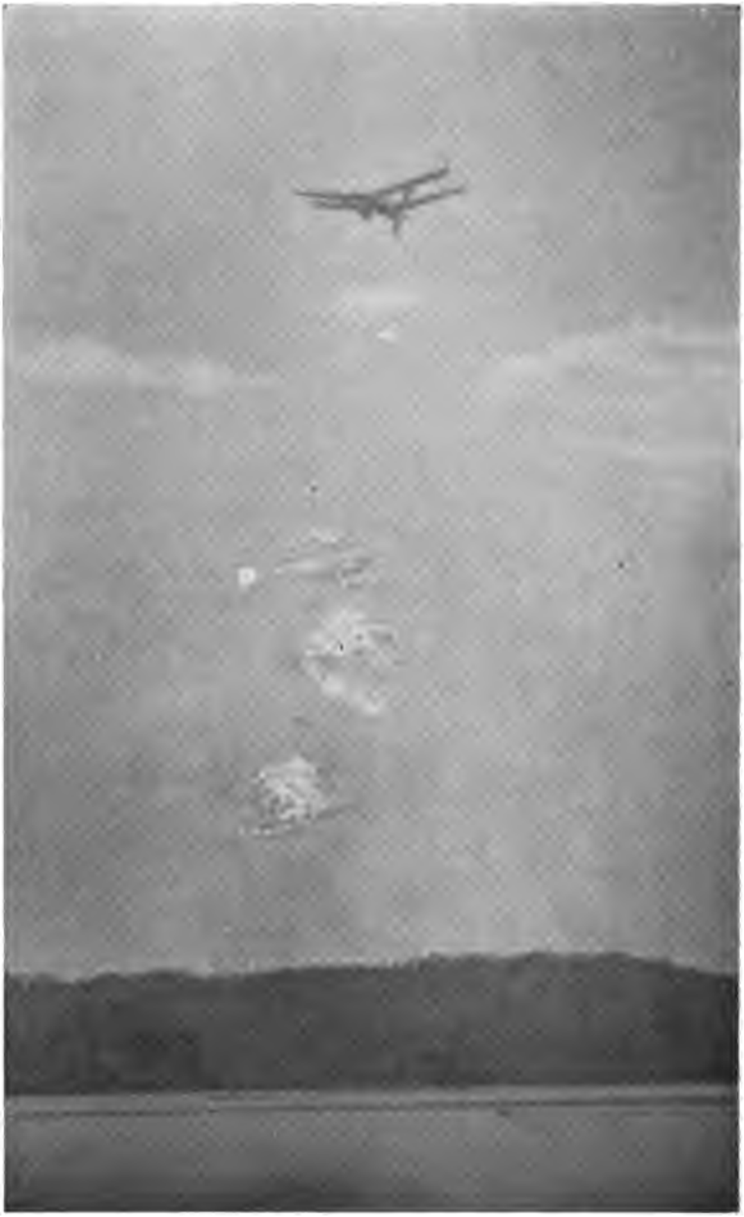
Hargrave of Australia attacked the flying-machine problem from the standpoint of a kite, communicating his results to the Royal Society of New South Wales. It is to him we owe the modern form of kite known as the "Hargrave box kite," which surpasses in stability all previous forms of kites. He also constructed successful flying-machine models on a small scale, using a store of compressed air as his motive power. He did not attempt to construct a large-sized apparatus or to go up into the air himself; so he still lives, to carry on researches that are of interest and value to the world.

SUCCESSFUL FLIGHT OF PROFESSOR LANGLEY'S MODEL

No one has contributed more to the modern revival of interest in flying-machines of the heavier-than-air type than our own Professor Langley, the late Secretary of the Smithsonian Institution. The constant failures and disasters of the past had brought into disrepute the whole subject of aërial flight by man; and the would-be inventor or experimenter had to face not only the natural difficulties of his subject, but the ridicule of a skeptical world. To Professor Langley is due the chief credit of placing this subject upon a scientific basis, and of practically originating what he termed the art of "aërodromics." In his epoch-making work on "Experiments in Aërodynamics," published in 1891 among the Smithsonian Contributions to Knowledge, he prepared the world for the recent advances in this art by announcing that—

> "The mechanical sustention of heavy bodies in the air, combined with very great speeds, is not only possible, but within reach of mechanical means we actually possess."

He also attempted to reduce his principles to practice by the construction of a



Langley's Aërodrome No. 5 in Flight, May 6, 1896

From instantaneous photograph by Alexander Graham Bell

large model of an aërodrome driven through the air by a steam-engine under the action of its own propellers. I was myself a witness of the memorable experiments made by Professor Langley on the 6th of May, 1896, with this large-sized model, which had a spread of wing of about 14 feet. No one who witnessed the extraordinary spectacle of a steam-engine flying with wings in the air, like a great soaring bird, could doubt for one moment the practicability of mechanical flight. I was fortunate in securing a photograph of this machine in full flight in the air, so that an automatic record of the achievement exists (page 4). The experiment realized the utmost hopes and wishes of Professor Langley at that time:

> "I have brought to a close," he says, "the portion of the work which seemed to be specially mine—the demonstration of the practicability of mechanical flight; and for the next stage, which is the commercial and practical development of the idea, it is probable that the world may look to others. The world indeed will be supine if it does not realize that a new possibility has come to it, and that the great universal highway over head is now soon to be opened."

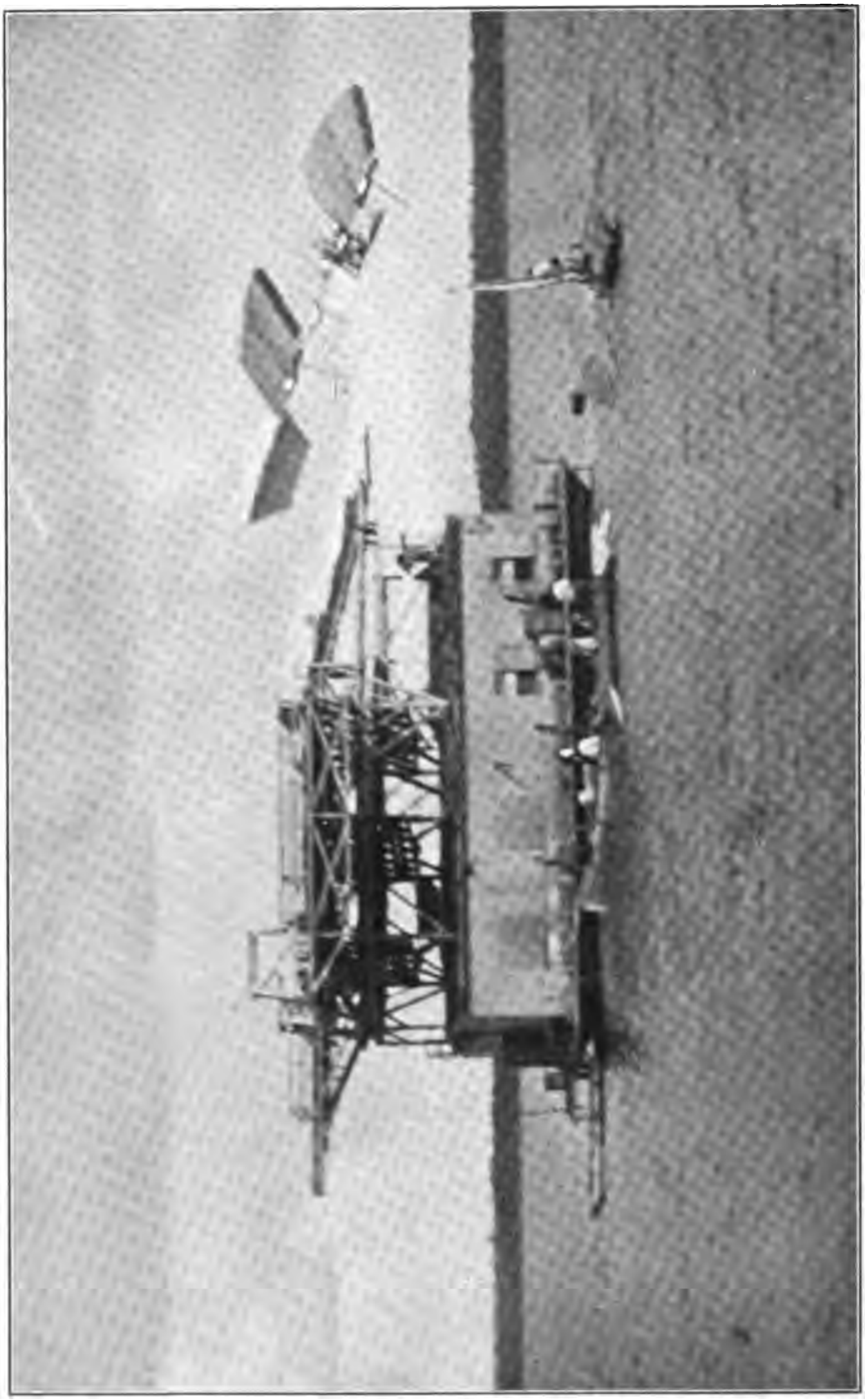
But the world was not satisfied with this position. It looked to Professor Langley himself to carry on the experiments to the point of actually transporting a human being through the air on an aërodrome like his model; and so, with the aid of an appropriation from the War Department of the United States, Professor Langley actually constructed a full-sized aërodrome, and found a man brave enough to risk his life in the apparatus—Mr Manley, of Washington, D. C.

LANGLEY'S EXPERIMENTS WITH HIS LARGE MACHINE

Great public interest was aroused; but Professor Langley did not feel justified in giving information to the public, and therefore to foreign nations, concerning experiments undertaken in the interests of the War Department. His own dislike to premature publicity coöperated with his conscientious scruples to lead him to deny the newspapers the opportunity of witnessing the experiments. But the newspapers insisted upon being represented. The correspondents flocked to the scene, and camped there for weeks, at considerable expense to their papers. They watched the house-boat containing the aërodrome by day and by night, and upon the least indication of activity within, newspaper reporters were on hand in boats. After long delay in hopes of securing privacy it was at last decided to try the apparatus; but the newspaper representatives, embittered by the attempts to exclude them, were bringing the experiments into public contempt. They nicknamed the apparatus "The Buzzard," and were all ready to presage defeat.

Two experiments were made; but on both occasions the apparatus caught in the launching ways and was precipitated into the water without having a chance to show what it could do in the air. The newspapers immediately announced to the world the failure of Professor Langley's machine and ridiculed his efforts. The fact of the matter is that the machine was never tried, and that there was no more reason for declaring it a failure than for deciding that a ship would not float that has never been launched. After having witnessed the successful flight of the large-sized model of 1896, I have no doubt that Professor Langley's full-sized aërodrome would have flown had it been safely launched into the air.

When the machine was for the second time precipitated into the water it was not much damaged by the accident. Professor Langley, of course, was more anxious about the fate of his intrepid assistant than of his machine, and followed Mr Manley into the house-boat to ascertain his condition. During this temporary withdrawal from the scene of the catastrophe the crew of a tugboat grappled the frail framework of the submerged aërodrome, and in the absence of any one competent to direct their efforts they broke the machine to pieces, thus ending the possibility of further experiments without the expenditure of much



The Accident to Langley's Aërodrome

From an instantaneous photograph loaned by the Smithsonian Institution. The machine caught in the launching ways and was injured, being precipitated into the water without having a chance to show what it could do in the air capital. The ridicule of the newspapers, however, effectually prevented Professor Langley from securing further financial aid, and, indeed, broke his heart. There can be little doubt that the unjust treatment to which he was exposed contributed materially to the production of the illness that caused his death.

He lived long enough, however, to know of the complete fruition of his hopes by others, and only two days before his death he had the gratification of receiving a communication from the newly formed Aëro Club of America recognizing and appreciating his efforts to promote mechanical flight. This communication read as follows:

RESOLUTIONS OF THE AERO CLUB OF AMERICA, ADOPTED JANUARY 20, 1906

> "WHEREAS our esteemed colleague, Dr S. P. Langley, Secretary of the Smithsonian Institution, met with an accident in launching his aërodrome, thereby missing a decisive test of the capabilities of this man-carrying machine, built after his models which flew successfully many times; and
>
> "WHEREAS, in that difficult experiment, he was entitled to fair judgment and distinguished consideration because of his important achievements in investigating the laws of dynamic flight, and in the construction of a variety of successful flying models: Therefore be it
>
> "*Resolved*, That the Aëro Club of America, holding in high estimation the contributions of Dr Langley to the science of aërial locomotion, hereby expresses to him its sincerest appreciation of his labors as a pioneer in this important and complex science; and be it further
>
> "*Resolved*, That a copy of these resolutions be sent to the Board of Regents of the Smithsonian Institution, and to Doctor Langley."

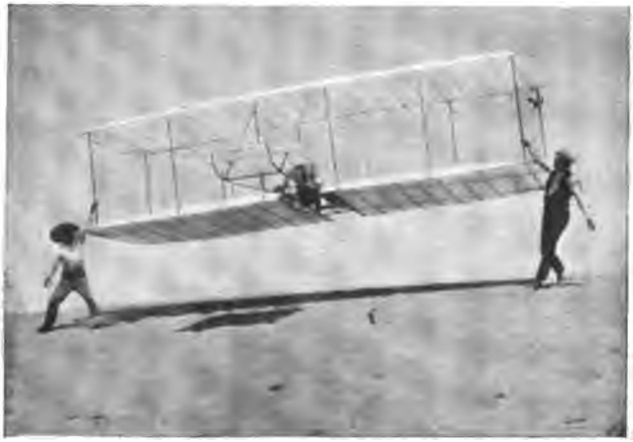
Professor Langley was on his deathbed when these resolutions were brought to his attention, and when asked what should be done with the communication his pathetic answer was, "*Publish it.*" To all who know his extreme aversion to publicity in any form this reply indicates how keenly he felt the misrepresentations of the press.

THE FIRST PRACTICAL FLYING MACHINE

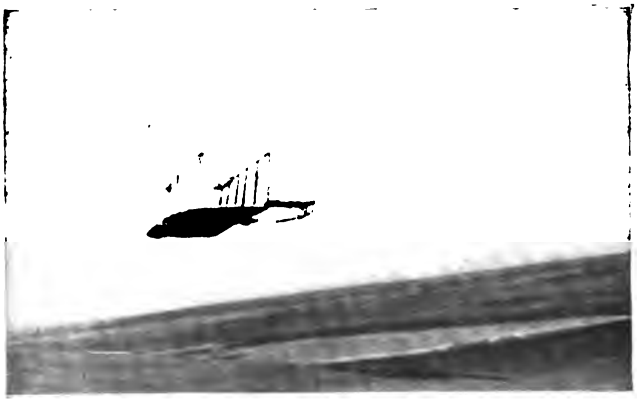
Both in the case of Lilienthal and Langley their efforts have not been in vain. Others have continued their researches, and today the world is in possession of the first practical flying-machine, the creation of the brothers Orville and Wilbur Wright, of Dayton, Ohio. Indeed, we have news from France that a second has just appeared, constructed by the same Santos Dumont to whom the world already owes the first practical dirigible balloon.

The Wright brothers began by repeating the gliding experiments of Lilienthal, with improved apparatus of the Hargrave type as modified by Chanute. After having made many successful glides through the air without a motor, they followed in the footsteps of Langley and propelled their machine by means of twin screws operated by engine power. They were successful in launching their apparatus into the air, and it flew, carrying one of them with it. Their machine has flown not once simply, but many times, and in the presence of witnesses; so that there can be no doubt that the first successful flying-machine has at last appeared. Specially successful flights were made on the 3d and 4th of October, 1905, which were referred to by the Wright brothers in a letter to the editor of *L'Aerophile* published in that journal January, 1906. They have also made a communication upon the subject to the Aëro Club of America, and have received the formal congratulations of that organization upon their success.

Each of the Wright brothers in turn has made numerous flights over their testing field near Dayton, Ohio, sometimes at an elevation of about 80 feet; at other times skimming over the field at a height of about ten feet from the ground. They have been able to circle over the field of operation, and even to describe in the air the figure eight, thus demonstrating their perfect control over their apparatus, both in the vertical and horizontal directions. They have succeeded in remaining continuously in the air for more than half an hour—thirty-eight minutes, in fact—and only came



Starting a Flight



A High Glide

The Wright Brothers' Gliding Machine

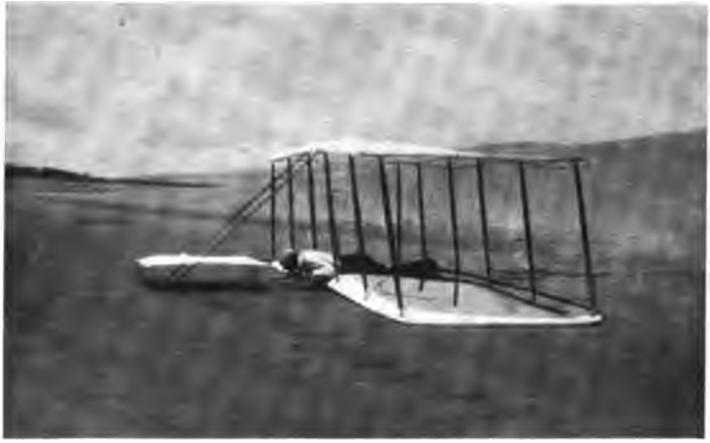
down on account of the exhaustion of their fuel supply. They state that the velocity attained was one kilometer per minute, or about thirty-seven miles an hour. The machine has not only sustained its own weight in the air during these trials, but has also carried a man and a gasoline engine weighing 240 pounds, exerting a force of from 12 to 15 horse-power, and in addition an extra load of 50 pounds of pig-iron. The apparatus complete, with motor, weighed no less than 925 pounds, while the supporting surfaces consisted of two superposed aëroplanes each measuring six by forty feet; so that the machine as a whole had a flying weight of nearly two pounds per square foot (1.9 pounds).

Thanks to the efforts of the Wright brothers, the practicability of aërial flight by man is no longer problematical. We can no longer consider as impossible that which has already been accomplished. America may well feel proud of the fact that the problem has been first solved by citizens of the United States.

A FEW NOTES OF PROGRESS IN THE CONSTRUCTION OF AN AERODROME

For many years past—in fact, from my boyhood—the subject of aërial flight has had a great fascination for me. Before the year 1896 I had made many thousands of still unpublished experiments having a bearing upon the subject, and I was therefore much interested in the researches of Professor Langley relating to aërodynamics. We were thrown closely together in Washington, and although we rarely conversed upon aërodynamics we knew that we had a subject of mutual interest and showed the greatest personal confidence in one another. I did not hesitate to show him my experiments; he did not hesitate to show me his. At least as early as 1894 Professor Langley visited me in my Nova Scotia home and witnessed some of my experiments; and in May, 1896, he reciprocated by inviting me to accompany him to Quantico, Virginia, and witness a trial of his large-sized model. The sight of

Soaring



Landing

Langley's steam aërodrome circling in the sky convinced me that the age of the flying-machine was at hand. Encouraged and stimulated by this remarkable exhibition of success, I quietly continued my experiments in my Nova Scotia laboratory in the hope that I, too, might be able to contribute something of value to the world's knowledge of this important subject.

Warned by the experiences of others, I have sought for a safe method of approach — a method that should risk human life as little as possible during the earlier stages of experiment. Experiments with aërodromes must necessarily be fraught with danger until man, by practical experience of the conditions to be met with in the air and of the means of overcoming them, shall have attained skill in the control of aërial apparatus. A man cannot even ride a bicycle without practice, and the birds themselves have to learn to fly. Man, not having any inherited instincts to help him in this matter, must first control his flight consciously, guided by knowledge gained through experiment. Skill can only be obtained by actual experience in the air, and this experience will involve accidents and disasters of various sorts before skill can be obtained. If these disasters should, as so often in the past, prove fatal to the experimenter, the knowledge obtained by the would-be aviator will be lost to the world, and others must begin all over again, instead of pursuing the subject where he left off, with the benefit of his knowledge and his experience. It is therefore of the utmost consequence to progress in the art of aviation that the first attempts to gain experience in the air should be made under such conditions of safety as to reduce to a minimum the liability to fatal results.

A MACHINE THAT WILL SUPPORT ITSELF AT LOW VELOCITY DESIRABLE

The Wright brothers' successful flying-machine travels at the rate of about thirty-seven miles an hour; and, judging from its great flying weight (nearly two pounds per square foot of supporting surface), it is unlikely that it could be maintained in the air if it had a very much less velocity. But should an accident happen to a body propelled through the air with the velocity of a railroad train, how about the safety of the occupants? Accidents will happen, sooner or later, and the chances are largely in favor of the first accident being the last experiment. While, therefore, we may look forward with confidence to the ultimate possession of flying-machines exceeding in speed the fastest railroad trains, it might be the part of wisdom to begin our first experiments at gaining experience in the air with machines traveling at such moderate velocities as to reduce the chances of a fatal catastrophe to a minimum. This means that they should be light-flying machines—that is, the ratio of weight to supporting surface should be small.

While theory indicates that the greater the weight in proportion to supporting surface consistent with flight, the more independent of the wind will the machine be, yet it might be advisable to begin, if possible, with such a moderate flying weight as to permit of the machine being flown as a kite. There would be little difficulty, then, in raising it into the air, and should an accident happen to the propelling machinery, the apparatus would descend gently to the ground; or the aviator could cast anchor, and his machine would continue flying, as a kite, if the wind should prove sufficient for its support. If it could fly, as a kite, in a ten-mile breeze, then a velocity of only ten miles an hour would be sufficient for its support as a flying-machine in calm air, while a less speed would suffice in heading into a moderate wind.

Such velocities would be consistent with safety in experiments, especially if the flights should be made over water instead of land, and at moderate elevations above the surface. Under such circumstances the inevitable accidents which are sure to happen during first experiments are hardly likely to be followed by more serious consequences than a ducking to the man and the immersion of the machine. If the man is able to swim and the machine to float upon water, little damage need be anticipated to either.

There are two critical points in every aërial flight—its beginning and its end. A flying-machine adapted to float upon water not only seems to afford a safe means of landing, but also promises a solution of that most difficult of problems—a safe method of launching the apparatus into the air. If the supporting floats are so formed as to permit of the machine being propelled over the surface of the water like a motor boat, then, if sufficient headway can be gained under the action of her aërial propellers, the machine can be steered upward into the air, rising from the water, after the manner of a water bird, in the face of the wind. This seems to be the safest method of gaining access to the air; but, of course, its practicability depends upon possibilities of lightness and speed yet to be demonstrated.

In any event, if the machine, man and all, is light enough to be flown as a kite, it can be towed out of the water into the air through the agency of a motor boat; and, upon land, it would not even be necessary for it to gain headway before rising, for in a supporting wind it would rise of itself into the air, if relieved of the weight of the man, and fly as a kite. It would then be a comparatively simple matter to lower the kite to a convenient height from the ground, and to hold it steadily in position by subsidiary lines.

while the aviator ascends a rope ladder to his seat in the machine. In this way the man would not be exposed to danger during the critical operation of launching the apparatus into the air, and by a converse process a safe landing could be effected without bringing the machine to the ground. The chance of injury to the machine itself would also be much lessened by relieving it of the weight of the man during the initial process of launching and the final process of bringing the machine down to the ground.

Such speculations as these of course are only justifiable upon the assumption that it is possible to construct an aërial vehicle large enough and strong enough to support a man and an engine in the air, and yet light enough to be flown as a kite in a moderate breeze with the man and engine and all on board. My experiments in Nova Scotia have demonstrated that this can be done; and I now therefore find myself seriously engaged in the attempt to reduce these ideas to practice by the actual construction of an aërodrome of the kite variety. The progress of experiment may be divided into three well-marked stages: the kite stage, the motor-boat stage, and the free flying-machine rising from the water.

THE KITE STAGE

In April, 1899, I made my first communication on the subject of kites to the National Academy of Sciences in a paper entitled "Kites with Radial Wings," which was reviewed, with illustrations, in the *Monthly Weather Review* for April, 1899 (vol. XXVI, pp. 154-155, plate XI). I made another communication to the National Academy on the 23d of April, 1903, upon "The Tetrahedral Principle in Kite Structure," which was published, with ninety-one illustrations and an appendix, in the NATIONAL GEOGRAPHIC MAGAZINE for June, 1903 (vol. XIV, pp. 220-251). The substance of the present address was presented in part to the National Academy of Sciences at their recent meeting in Boston, Massachusetts, November 21, 1906. The experiments referred to, which were undertaken at first for my own pleasure and amusement, have gradually assumed a serious character, from their bearing upon the flying-machine problem.

The word "kite" unfortunately is suggestive to most minds of a toy—just as the telephone at first was thought to be a toy; so that the word does not at all adequately express the nature of the enormous flying structures employed in some of my experiments. These structures were really aërial vehicles rather than kites, for they were capable of lifting men and heavy weights into the air. They were flown after the manner of kites, but their flying cords were stout manila ropes. They could not be held by hand in a heavy breeze, but had to be anchored to the ground by several turns of the ropes around stout cleats, like those employed on steamships and men-of-war.

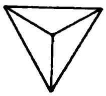
One of the great difficulties in making a large structure light enough to be flown as a kite has been pointed out by Professor Simon Newcomb in an article in *McClure's Magazine*, published in September, 1901, entitled "Is the Air-Ship Coming?" and this difficulty had so much weight with him at that time as to lead him to the general conclusion that—

> "The construction of an aërial vehicle which could carry even a single man from place to place at pleasure requires the discovery of some new metal or some new force."

This conclusion the Wright brothers, and now Santos Dumont, have demonstrated to be incorrect; but Professor Newcomb's objections undoubtedly have great force, and reveal the cause of failures of attempts to construct large-sized flying-machines upon the basis of smaller models that actually flew. Professor Newcomb shows that where two aërial vehicles are made exactly alike, only differing in the scale of their dimensions, the ratio of weight to supporting surface is greater in the larger one than in the smaller, the weight increasing as the cube of the dimensions, whereas the supporting surfaces only increase as the squares. From this the conclusion is obvious that if we make our structure large enough it will be too heavy to fly—even by itself—far less be the means of supporting an additional load like a man and an engine for motive power. This conclusion is undoubtedly correct in the case of structures that are "exactly alike excepting in their dimensions," but it is not true as a general proposition.

EVADING AN OLD LAW

A small bird could not sustain a heavy load in the air; and while it is true that a similar bird of double the dimensions would be able to carry a less proportionate weight, because it is itself heavier in proportion to its wing surface than the smaller bird—eight times as heavy, in fact, with only four times the wing surface—still it is conceivable that a flock of small birds could sustain a heavy load divided equally among them; and it is obvious that in this case the ratio of weight to wing surface would be the same for the whole flock as for the individual bird. If, then, we build our large structure by combining together a number of small structures each light enough to fly, instead of simply copying the small structure upon a larger scale, we arrive at a compound or cellular structure in which the ratio of weight to supporting surface is the same as that of the individual units of which it is composed, thus overcoming entirely the really valid objections of Professor Newcomb to the construction of large flying-machines.



Unit cell having the form of the regular tetrahedron.

In my paper upon the tetrahedral principle in kite structure I have shown that a framework having the form of a tetrahedron possesses in a remarkable degree the properties of strength and lightness. This is specially the case when we adopt as our unit structure the form of the regular tetrahedron, in which the skeleton frame is composed of six rods of equal length, as this form seems to give the maximum of strength with the minimum of material. When these tetrahedral frames or cells are connected together by their corners they compose a structure of remarkable rigidity, even when made of light and fragile material, the whole structure possessing the same properties of strength and lightness inherent in the individual cells themselves (page 12).

The unit tetrahedral cell yields the skeleton form of a solid, and it is bounded by four equal triangular faces. By covering two adjoining faces with silk, or other material suitable for use in kites, we arrive at the unit "winged cell" of the compound kite, the two triangular surfaces in their flying position resembling a pair of wings raised with their points upward, the surfaces forming a dihedral angle (Fig. A, p. 13).

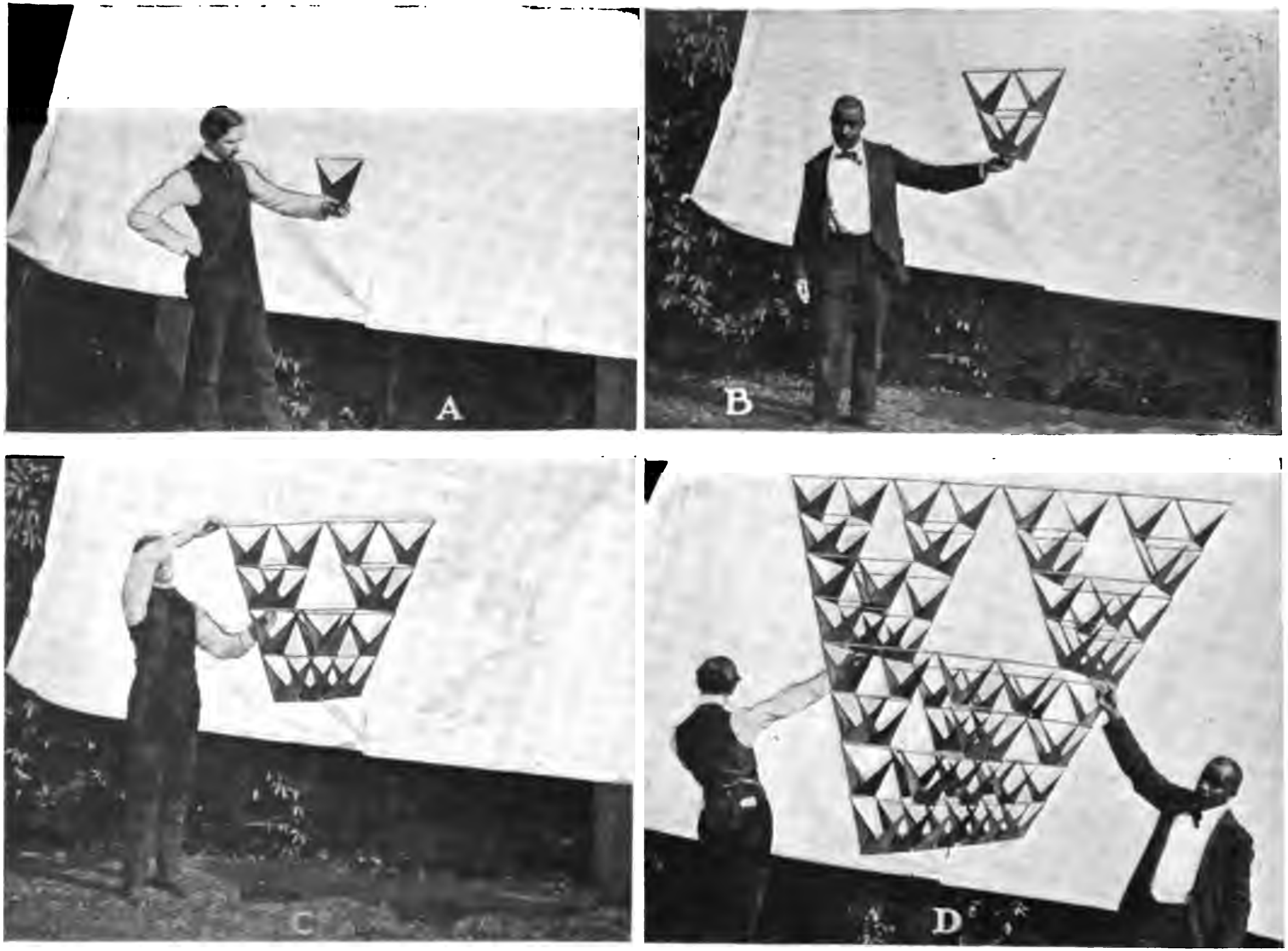
Four of these unit cells, connected together at their corners, form a four-celled structure having itself the form of a tetrahedron containing in the middle an empty space of octahedral form equal in volume to the four tetrahedral cells themselves (Fig. B, p. 13).

In my paper I showed that four of these four-celled structures connected at their corners resulted in a sixteen-celled structure of tetrahedral form containing, in addition to the octahedral spaces between the unit cells, a large central space equivalent in volume to four of the four-celled structures (Fig. C, p. 13).

In a similar manner four of the sixteen-celled structures connected together at their corners form a sixty-four-celled structure (Fig. D, p. 13).

Four of the sixty-four-celled structures form a two hundred and fifty-six-celled structure, etc., and in each of these cases an empty space exists in the center equivalent to half of the cubical contents of the whole structure, in addition to spaces between the individual cells and minor groups of cells.

Kites so formed exhibit remarkable stability in the air under varying conditions of wind, and I stated in my paper that the kites which had the largest central spaces seemed to be the most stable in the air. Of course, these were the



A. Single-winged cell. B. Four-celled kite. C. Sixteen-celled kite. D. Sixty-four-celled kite

On this, the hollow plan of construction, an empty space appears in the middle of each kite, B, C, or D, equivalent in volume to one-half of the cubical contents of the whole structure

64-celled Tetrahedral Kite Flying from Flag-pole

Photograph by D. G. McCurdy

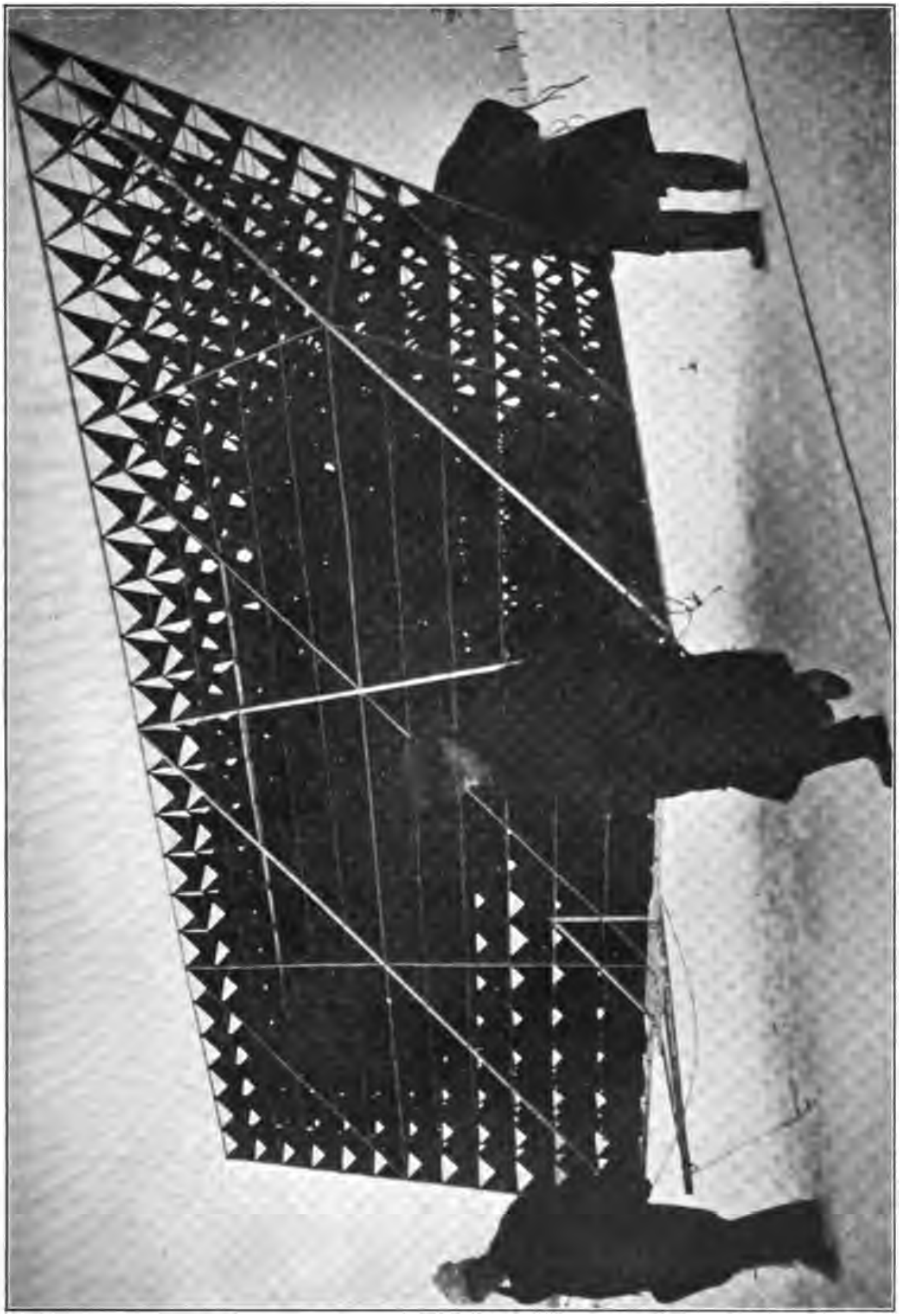
structures that were composed of the largest number of unit cells, and I now have reason to believe that the automatic stability of these kites depends more upon the number of unit cells than upon the presence of large empty spaces in the kites; for I have found, upon filling in these empty spaces with unit cells, that the flying qualities of a large kite have been greatly improved. The structure, so modified, seems to fly in as light a breeze as before, but with greatly increased lifting power, while the gain in structural strength is enormous.

I had hitherto supposed that if cells were placed directly behind one another without providing large spaces between them comparable to the space between the two cells of a Hargrave box kite, the front cells would shield the others from the action of the wind, and thus cause them to lose their efficiency; but no very marked effect of this kind has been observed in practice. Whatever theoretical interferences there may be, the detrimental effect upon the flying qualities of a kite are not, practically, obvious, while the gain in structural strength and in lifting power outweigh any disadvantages that may exist. I presume that there must be some limit to the number of cells that can be placed in close proximity to one another without detrimental effect, but so far my experiments have not revealed it.

EXPERIMENTS WITH "THE FROST KING"

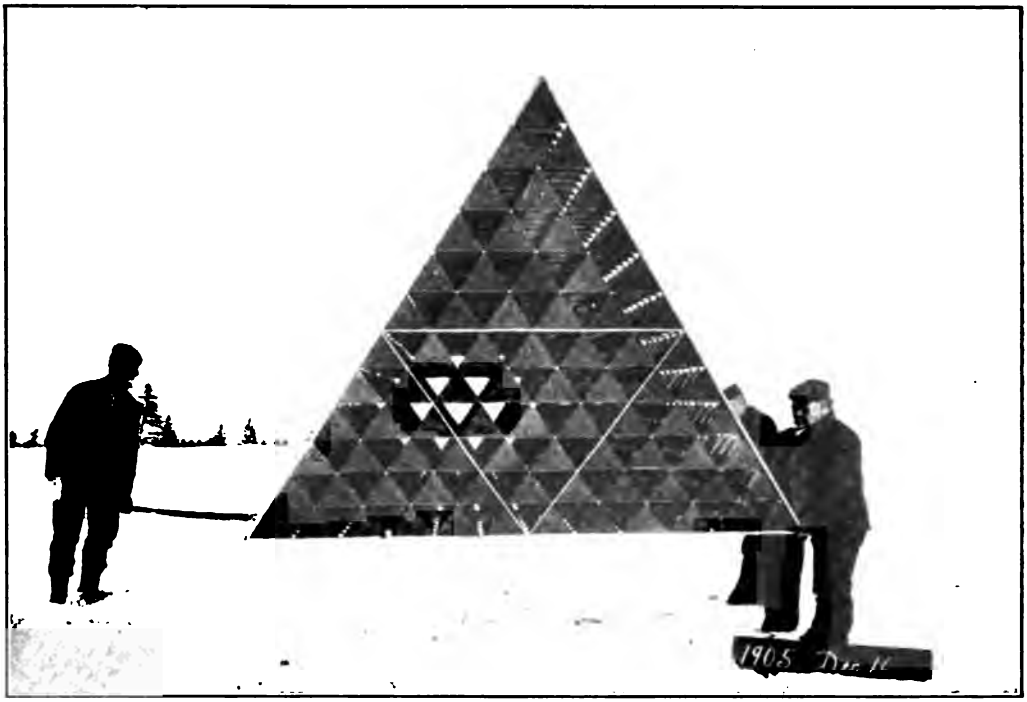
To test the matter, I put together into one structure all the available winged cells I had in the laboratory—1,300 in number. These were closely attached together, without any other empty spaces in the structure than those existing between the individual cells themselves when in contact at their corners.

The resulting kite, known as "The Frost King" (pages 15 and 16), consisted of successive layers or strata of cells closely superposed upon one another. The lowest layer, or floor of the structure, consisted of 12 rows of 13 cells each. The cells forming each row were placed side by side, attached to one another by their upper corners, and the 12 rows were placed one behind the other, the rear corners of one row being attached to the front corners of the row immediately behind. The next stratum above the floor had eleven rows of 14 cells; the next, 10 rows of 15 cells, etc., each successive layer increasing in lateral dimensions and diminishing in the fore-and-aft direction; so that the top layer, or roof, consisted of a single row of 24 cells placed side by side. One would imagine that a closely packed mass of cells of this kind, 1,300 in number, would have developed some difficulty in flying in a moderate breeze if the cells interfered with one another to any material extent; but this kite not only flew well in a breeze



Carrying the Frost King on to the Testing Ground

This kite was composed of 1,300 light winged cells closely massed together. Photograph by E. H. Cunningham



Side View of the Frost King, showing how closely the cells are massed together

Photograph by E. H. Cunningham

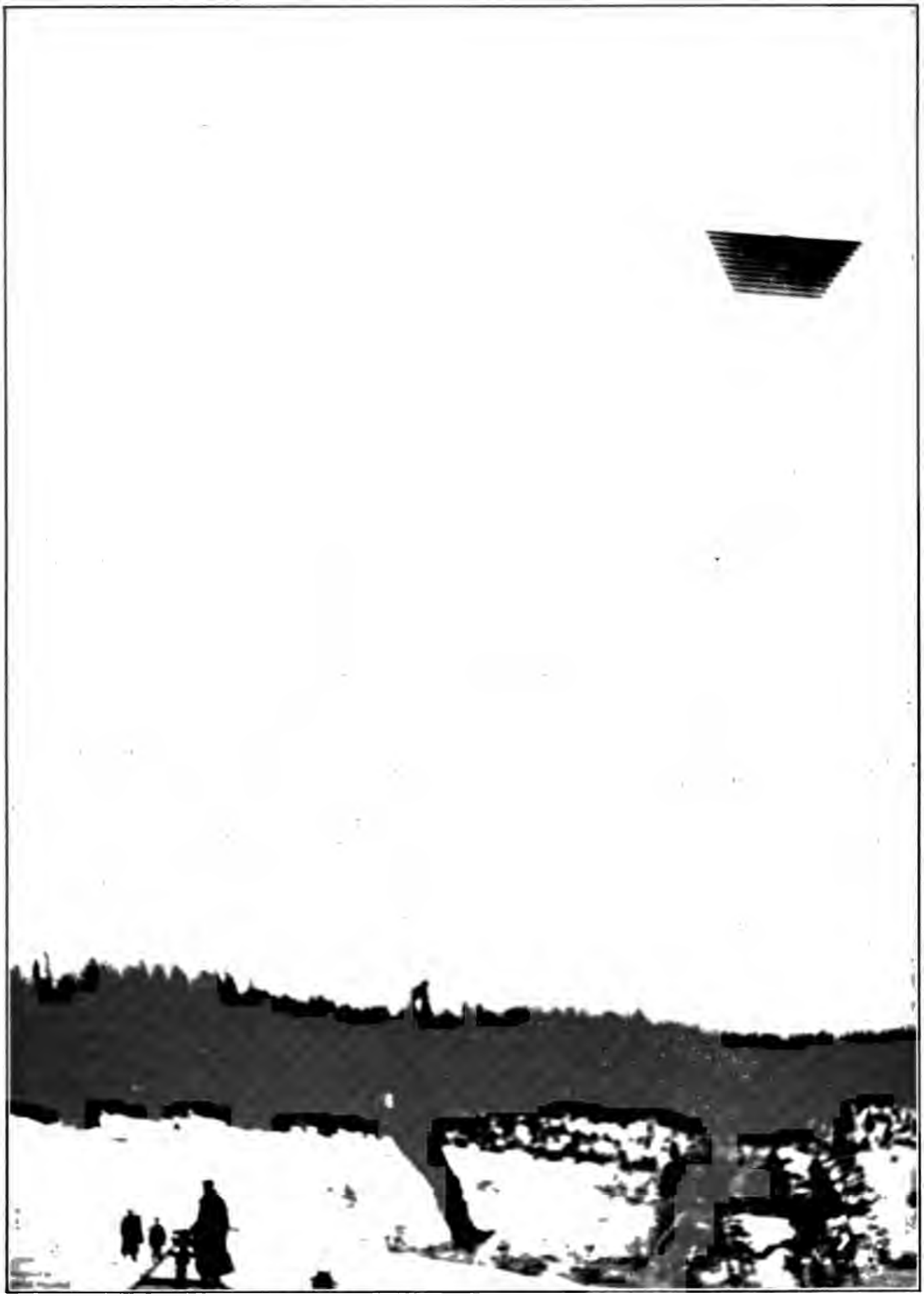
estimated at not more than about 10 miles an hour because it did not raise white caps; but carried up a rope ladder, several dangling ropes 10 and 12 meters long, and more than 200 meters of manilla rope used as flying lines, and, in addition to all this, supported a man in the air (page 17).

The whole kite, impedimenta and all, including the man, weighed about 131 kgs (288 pounds), and its greatest length from side to side was 6 meters at the top and three meters at the bottom. The sloping sides measured 3 meters, and the length from fore to aft at the square bottom was 3 meters. It is obvious that this kite might be extended laterally at the top to twice its length without forming an immoderately large structure. It would then be 12 meters on the top (39 feet) and 9 meters on the bottom from side to side, without changing the fore-and-aft dimensions or the height. It would then contain more than double the number of cells, and so should be able to sustain in the air more than double the load; so that such a structure would be quite capable of sustaining both a man and an engine of the weight of a man and yet be able to fly as a kite in a breeze no stronger than that which supported the "Frost King."

An engine of the weight of a man could certainly impart to the structure a velocity of 10 miles an hour, the estimated velocity of the supporting wind, and thus convert the kite into a free flying-machine. The low speed at which I have been aiming for safety's sake is therefore practicable.

HORIZONTAL AEROPLANES FOUND INSTABLE

In the "Frost King" and other kites composed exclusively of tetrahedral winged cells there are no horizontal sur-



The Frost King in the Air, Flying in a Ten-mile Breeze, and Supporting a Man on the Flying Rope

During the experiment the rope straightened under the pull of the kite, and the man was raised to a height of 30 or 40 feet. He was in great peril, but fortunately was brought down safely. Photograph by Alexander Graham Bell faces (or rather surfaces substantially horizontal, as in ordinary kites), but the framework is admirably adapted for the support of such surfaces. Horizontal aëroplanes have much greater supporting power than similar surfaces obliquely arranged, and I have made many experiments to combine horizontal surfaces with winged cells with greatly improved results, so far as lifting power is concerned. But there is always an element of instability in a horizontal aëroplane, especially if it is of large size, whereas kites composed exclusively of winged cells are wonderfully steady in the air under varying conditions, though deficient in lifting power; and the kites composed of the largest number of winged cells seem to be the most stable in the air.

In the case of an aëroplane of any kind the center of air pressure rarely coincides with the geometrical center of surface, but is usually nearer the front edge than the middle. It is liable to shift its position, at the most unexpected times, on account of some change in the inclination of the surface or the direction of the wind. The change is usually small in steady winds, but in unsteady winds great and sudden changes often occur.

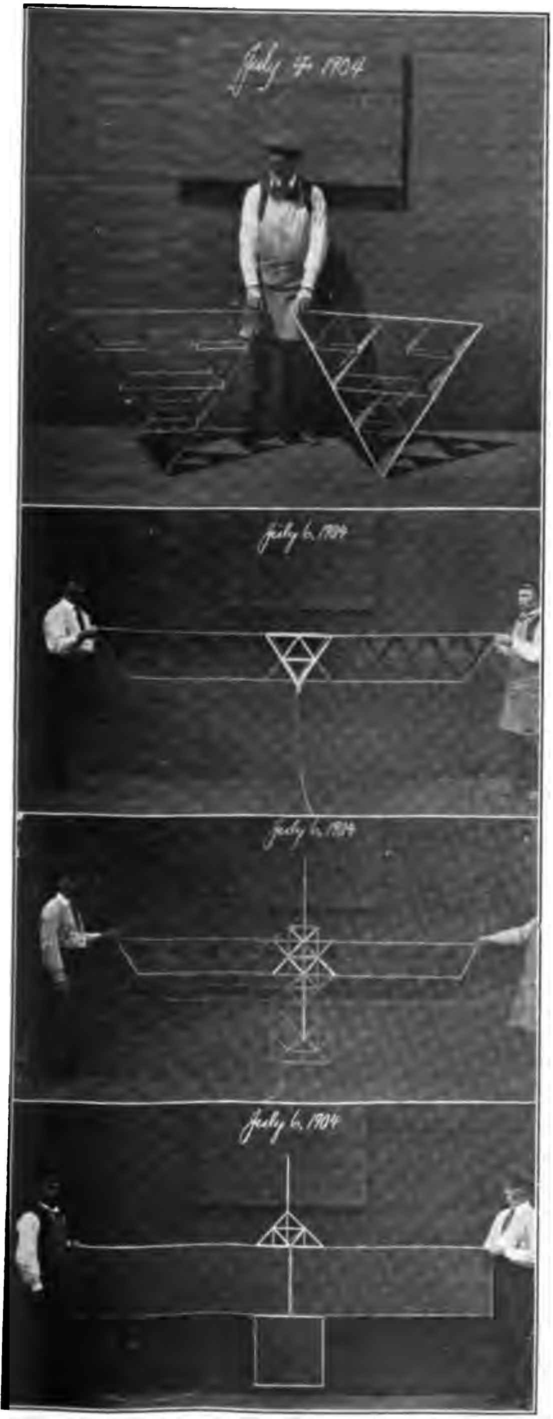
The extreme possible range of fluctuation is of course, from the extreme front of the aëroplane to the rear, or *vice versa*, and the possible amount of change, therefore, depends upon the dimensions of the aëroplane, especially in the fore-and-aft direction. With a large aëroplane the center of pressure may suddenly change to such an extent as to endanger the equilibrium of the whole machine, whereas with smaller aëroplanes, especially those having slight extension in the fore-and-aft direction, the change, though proportionally as great, is small in absolute amount. Where we have a multitude of small surfaces well separated from one another, as in the tetrahedral construction, it is probable that the resultant center of pressure for the whole kite can shift to no greater extent than the centers of pressure of the individual surfaces themselves. It is, therefore, extremely unlikely that the equilibrium of a large kite could be endangered by the shifting of the centers of pressure in small surfaces within the kite. This may be the cause of the automatic stability of large structures built of small tetrahedral cells. If so, one principle of stability would be: *Small surfaces, well separated, and many of them.* The converse proposition would then hold true if we desired to produce instability and a tendency to upset in a squall, namely: *Large surfaces, continuous, and few of them.*

HARGRAVE BOX KITES AND TETRAHEDRAL KITES COMPARED

Another source of danger with large continuous surfaces is the fact that a sudden squall may strike the kite on one side, lifting it up at that side and tending to upset it; but the compound tetrahedral structure is so porous that a squall passes right through and lifts the other side as well as the side first struck; so that the kite has not time to be upset before the blow on one side is counterbalanced by a blow on the other. I have flown a Hargrave box kite simultaneously with a large kite of many tetrahedral cells in squally weather for the purpose of comparing them under similar conditions. The tetrahedral structure often seemed to shiver when struck by a sudden squall, whereas the box kite seemed to be liable to a swaying or tipping motion that would be exceedingly dangerous in a structure of large size forming part of a flying-machine.

Another element of stability in the tetrahedral structure lies in the fact that the winged surfaces are elevated at a greater angle above the horizon than 45°.

Supposing the wings of a cell to be opened out until they are nearly flat, or at least until they each make a comparatively small angle with the horizon—say 20°—then, if from any cause the cell should tip so as to elevate one wing (say to 25°) and depress the other (say to 15°), the lifting power of the wind will be increased upon the elevated wing and diminished on the depressed wing;



1. **Two 16-celled Tetrahedral Kites, the one on the right protected by a beading of wood around the outer edges. 2, 3, 4. Oionos Kite with fixed tail. 2. Front view. 3. Bottom view. 4. Top view**

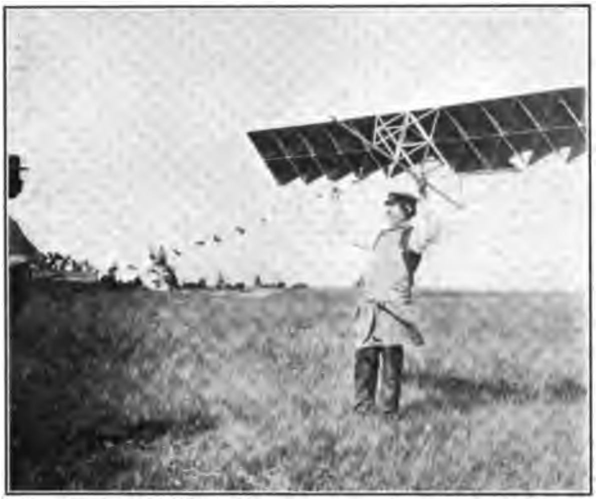
so that there would be no tendency to a recovery of position, but the very reverse. The pressure of the wind would tend to increase the tipping action and favor the production of oscillation and a tendency to upset. The lifting power of the wind upon a surface inclined at 10° is less than at 20°, and greater at 25° than 20°. The more the wings are opened out and the flatter they become, the more essentially unstable is the arrangement in the air.

Now suppose the wings to be raised until they are nearly closed, or at all events till they make a small angle with the vertical (say 70° from the horizontal), then, if from any cause the cell should tip so as to elevate one wing (say to 75°) and depress the other (say to 65°), the lifting power of the wind will be increased upon the depressed wing and diminished on the elevated wing; for the lifting power of the wind is greater at 65° than at 70° and less at 75°. Thus the moment a tipping action begins the pressure of the wind resists it, and an active force is invoked tending to restore the structure to its normal position. The more the wings are raised and the more they approach the perpendicular position, the more stable essentially is the arrangement in the air.

The dividing line between these two opposite conditions seems to be drawn about the angle of 45°. As the tetrahedral wing surfaces make a greater angle than this with the horizontal, they constitute an essentially stable arrangement in the air, whereas a horizontal surface represents the extreme of the undesirable unstable condition.

AUTOMATIC STABILITY

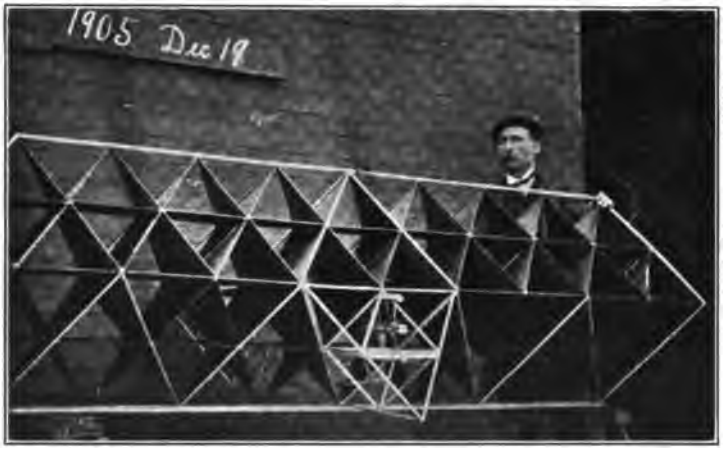
These considerations have led me to prefer a structure composed of winged tetrahedral cells alone, without horizontal surfaces either large or small, although the lifting power is less than when horizontal surfaces are employed, because the factor of safety is greater. One of the chief causes that have led to disasters in the past has been a lack of stability in the air. Automatic stability under varying conditions is surely of the very first consequence to safety, for



Method of Flying the Oionos Kite

Pieces of red silk are attached to several meters of the flying cord with the object of rendering the direction of the cord visible on the photograph plate

what would it profit a man were he to gain the whole world and lose his own equilibrium in the air? A kite composed exclusively of multitudinous winged cells seems to possess this property of automatic stability in a very marked degree. If, then, its lifting power is sufficient for our purpose, there is no necessity for the introduction of a factor of danger by the addition of horizontal surfaces. Of course, the addition of such surfaces would enable us to secure the desired lifting power with a smaller, and therefore lighter, structure, and this would be of advantage if we could be sure of its stability in the air.



Oionos Kite with Movable Tail Controlled by Swinging Head-load of Lead

When released in the air at a considerable elevation it acts very much like a soaring bird, moving forward against the wind or swinging around in large circles. It is then, in effect, a free gliding machine, which acquires considerable velocity in the horizontal direction, while descending gently in the vertical direction. The head-load gives the machine a slight tendency to dive, which is resisted by the steering action of the tail when headway is gained. The moment the head is depressed, as in diving, the weight swings forward, thus automatically causing the elevation of the tail

In employing tetrahedral winged cells alone upon the hollow plan of construction in which large empty spaces occurred within the kite, a practical difficulty was encountered arising from the enormous size of the structure required for the support of a man, combined with the increasing weakness of the structure as it increased in size. The discovery that the cells may be closely massed together without marked injurious effects has completely remedied this difficulty; for upon this plan not only is the structural strength improved by an increase of size, but the lifting power increases with the cube of the dimensions; so that a very slight increase in the dimensions of a large kite increases very greatly its lifting power. We now have the possibility of building structures composed exclusively of tetrahedral winged cells that will support a man and an engine in a breeze of moderate velocity without the necessity of constructing a kite of immoderate size. The experiments with the "Frost King" made in December, 1905, satisfied me upon this point and brought to a close my experiments with kites.

CONCLUSION

Since December, 1905, my attention has been directed to other points necessary to be considered before an aërodrome of the kite variety can be made, and to the assembling of the materials for its manufacture.

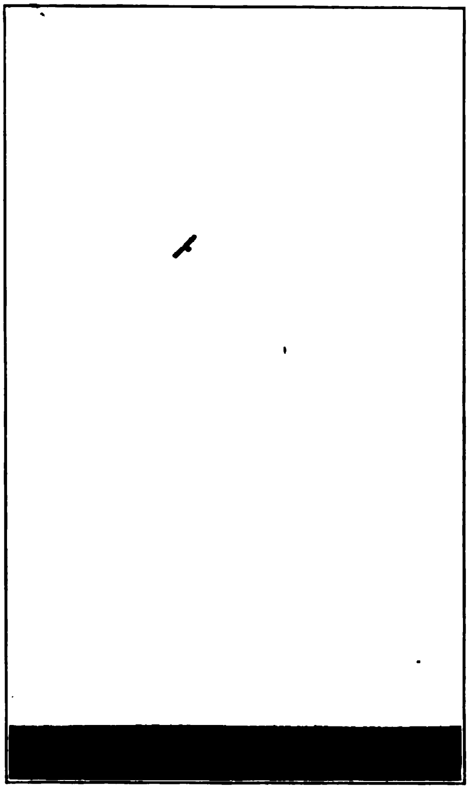
I have had to improve and simplify the method of making the winged cells themselves. Through the agency of Mr Hector P. McNeil, superintendent of the Volta laboratory, Washington, D. C., who is now taking up the manufacture of tetrahedral cells as a new business, I am now able to obtain cells constructed largely by machinery, and with stamped metal corners to hold the rods together. The process of tying the cells and parts of cells together had proved to be very laborious and expensive, and the process was not suited to unskilled persons. By the new process most of the work is done by machinery, and no skill is required to connect the cells together.

I have also had to go into the question of motor construction—a subject with which I am not familar—and while waiting for the completion of the material required for the aërodrome I have been carrying on experiments to test the relative efficiency of various forms of aërial propellers.

I have also been occupied with the details of construction of a supporting float adapted for propulsion over the water as a motor boat and also adapted to form the body of the flying-machine when in the air.

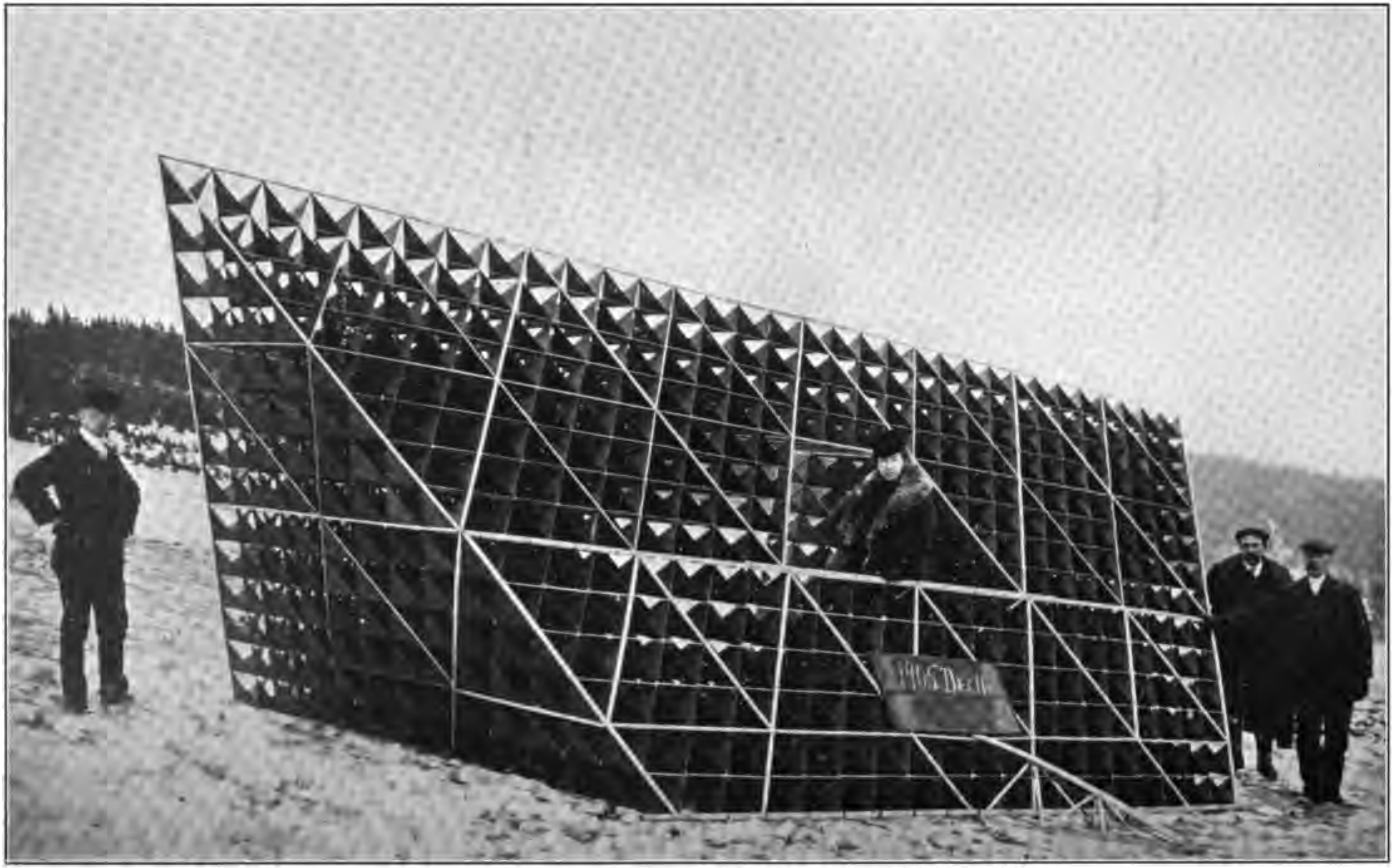
BOATS DRIVEN BY AERIAL PROPELLERS

Of course, it would be premature for me to enter into any description of experiments that are still in progress, or to submit plans for an aërodrome which are still under discussion. I shall therefore simply say, in conclusion, that I have recently been making experiments in propelling, by means of aërial propellers, a life-raft supported, catamaran fashion, on two metallic cylinders. The whole arrangement, with a marine motor on board, is exceedingly heavy, weighing over 2,500 pounds, and it is sunk so low



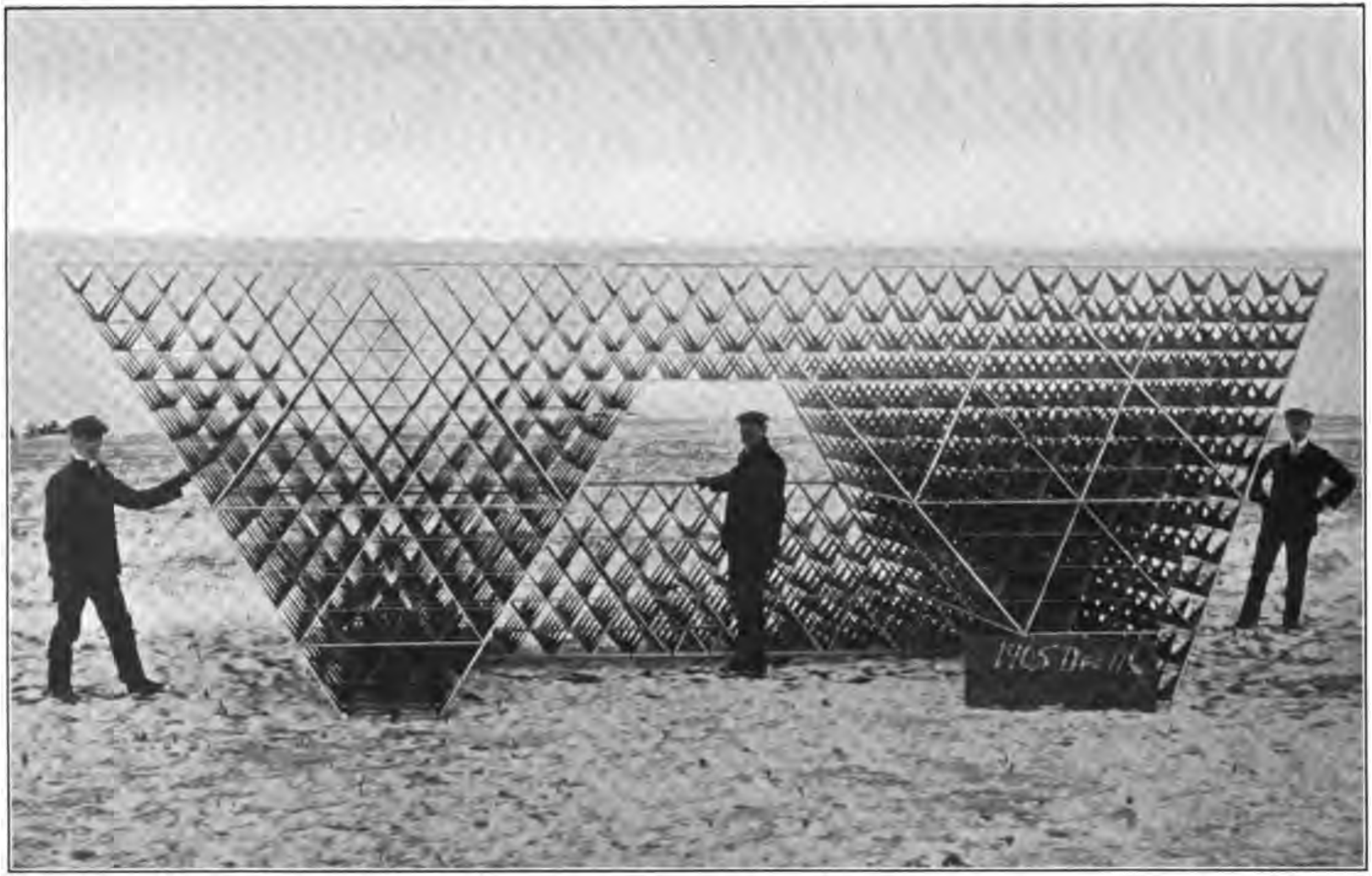
"Oionos" Kite in the Air

This name was applied by the ancient Greeks to the great solitary soaring birds, from which they drew their auguries



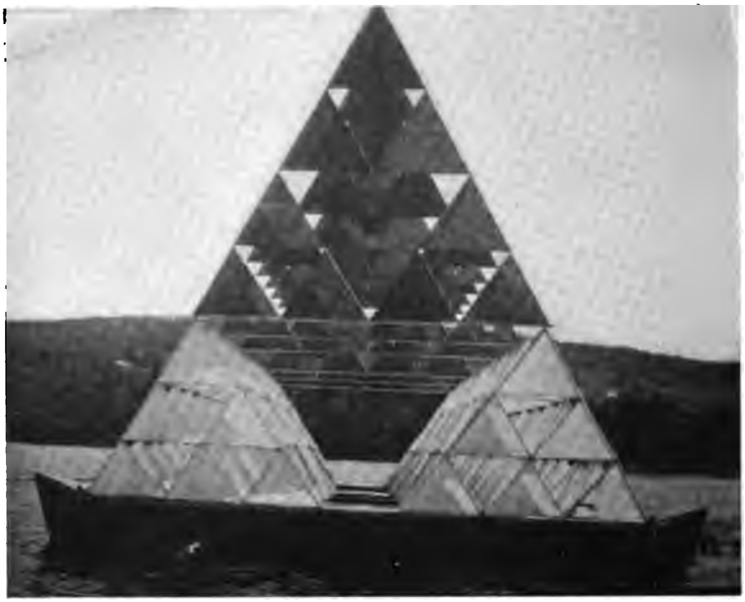
Kite "Siamese Twins" Seen from the Front

This kite was supported in the air by a strong wind exceeding, probably, 25 miles an hour. It was too heavy to be flown in a moderate breeze



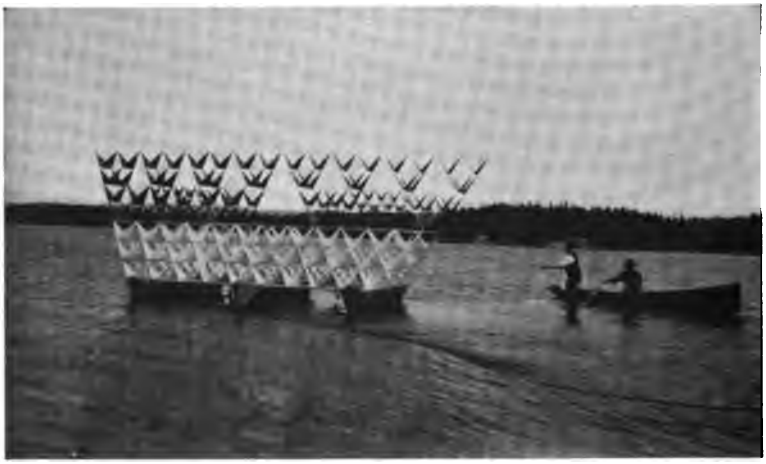
Kite "Siamese Twins," Seen from the Rear, Looking Inside Kite

Composed of two distinct kites connected by a bridge, or truss, of strong cells, well beaded, for support of man



Side View of Mabel II

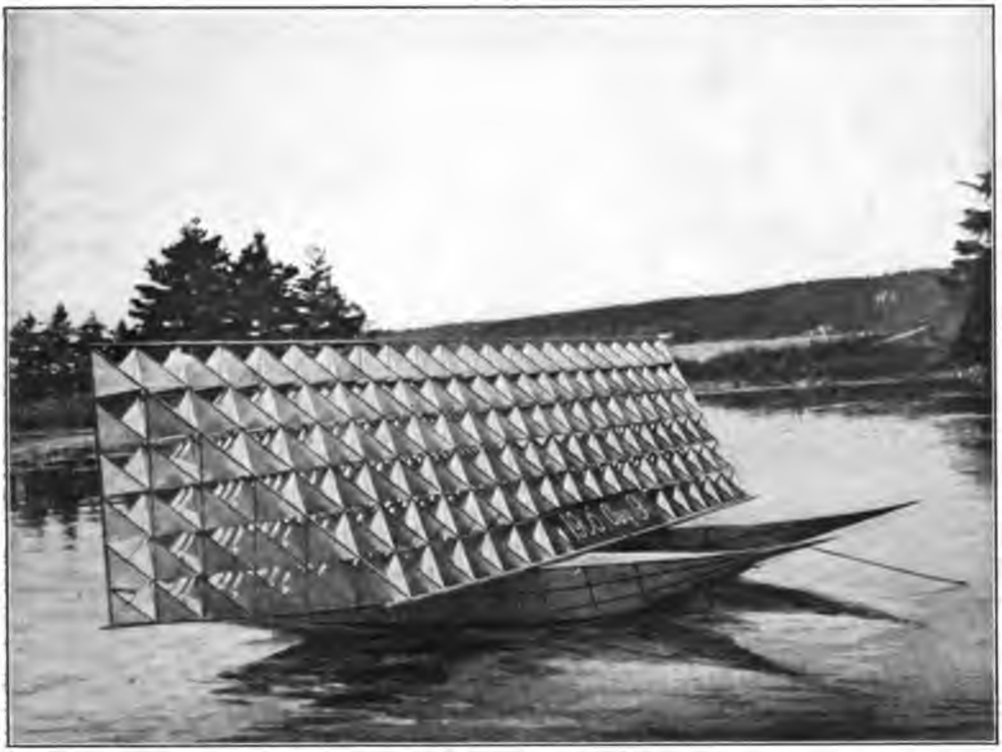
A floating kite supported upon three boat-like floats formed of tetrahedral cells and covered completely with oil-cloth. In September, 1903, this kite was raised into the air by being towed by a steamboat against the wind



Photos by Gilbert H. Grosvenor

Mabel II Outlined against Sky showing Bird-wing Effect

For experiments with this kite see "The Tetrahedral Kites of Dr Alexander Graham Bell," by Gilbert H. Grosvenor, *Popular Science Monthly*, December, 1903



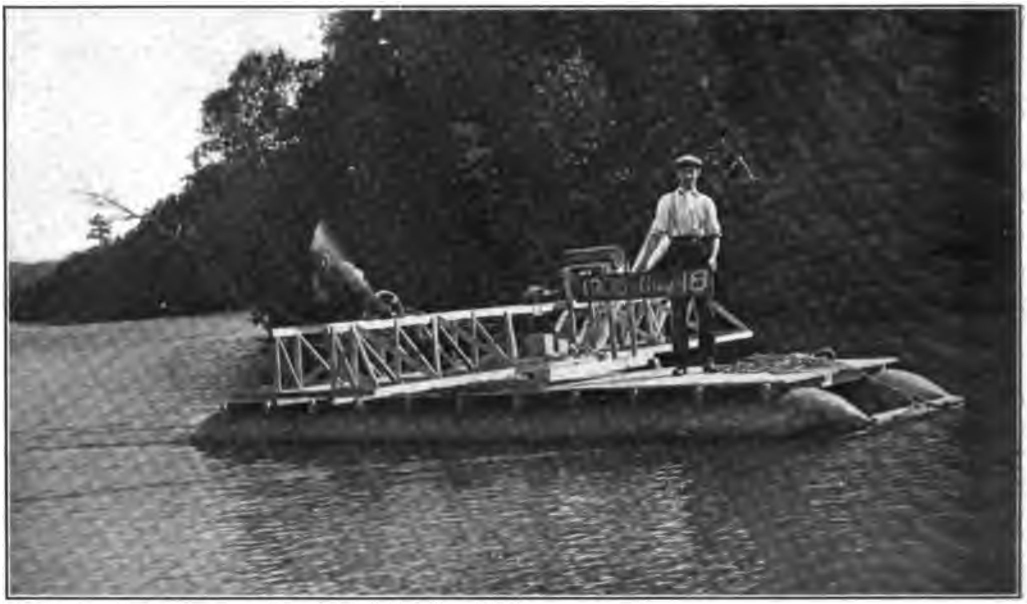
A Floating Kite, adapted to be Towed Out of the Water

Kite consists of a bridge, or truss, of tetrahedral cells with wings of Japanese waterproof paper upon two floats of light framework covered with oilcloth. A stout towing pole extends laterally across the lower part of the wing-piece at the front. Photograph by Douglas McCurdy

that the water level rises at least to the middle of the supporting cylinders, so that the raft is not at all adapted for propulsion and cannot attain great speed. The great and unnecessary weight of this machine has led to an interesting and perhaps important discovery that might have escaped attention had the apparatus been lighter and better adapted for propulsion (page 26).

Under the action of her aërial propellers, this clumsy raft is unable to attain a higher speed than four miles an hour; and yet she is able to face a sixteen-mile white-cap breeze and make headway against it, instead of drifting backward with the wind. Under such circumstances her speed is materially reduced; but the point I would direct attention to is this: that she is not stopped by a current of air moving with very much greater velocity than her maximum possible speed in a calm. Of course, there would be nothing remarkable about this if her propellers were acting in the water instead of the air; but they were not. They acted exclusively in the air, and the water was only an additional resistance to be overcome.

It is worthy of note in this connection that the rapid rotation of the propellers yield a theoretical efficiency of thirty or forty miles an hour, and that the mass of the machine and the resistance of the water drag this down to an actual performance of only four miles; so that at first sight it appears probable that the effect noted may be a result of the



"The Ugly Duckling"

A raft supported upon metallic cylinders and propelled by aërial propellers. Above illustration shows raft propelled by small gasoline motor. In subsequent experiments referred to in the text, the bridge, or truss, supporting the propellers was raised considerably above the level of the platform, and the engine employed was a four-cylinder water-cooled marine motor weighing 650 pounds. This caused the metallic floats to be sunk to their middle points; but the floats were not connected together at their ends, as shown above

greater slip of the propellers acting in a calm. I am inclined to think, however, that this explanation is insufficient, and would suggest the following as more probable:

The enormous mass of the moving body enables it to acquire very considerable momentum with slight velocity, whereas the opposing current of air has such slight mass that it cannot acquire an equal momentum with a very much higher velocity.

If two bodies of unequal mass, moving with equal but opposite velocities, come into collision with one another, then the heavier body will not be completely stopped by the lighter. It will make headway against the resistance of the other, even though the lighter should possess superior velocity, provided, of course, that it has a sufficient superiority of mass. We are here dealing with momentum (mv), not velocity (v) alone. The body having the greatest momentum will be the victor in the struggle, whatever the actual velocities may be.

The suggestiveness of this result lies in its application to the flying-machine problem. A balloon, on account of its slight specific gravity, must ever be at the mercy of the wind. In order to make any headway against a current of air, it must itself acquire a velocity superior to the wind that opposes it. On the other hand, it is probable that a flying-machine of the heavier-than-air type, at whatever speed it moves, will be able to make headway against a wind of much greater velocity, provided its momentum is greater than the momentum of the air that opposes it.

APPENDIX A

DETAILS CONCERNING THE KITE "FROST KING"

Number of Cells in the "Frost King"

Layers of cells.	Number of rows.	Number of cells in each row.	Number of cells in each layer.
1st layer	1	24	24
2d layer	2	23	46
3d layer	3	22	66
4th layer	4	21	84
5th layer	5	20	100
6th layer	6	19	114
7th layer	7	18	126
8th layer	8	17	136
9th layer	9	16	144
10th layer	10	15	150
11th layer	11	14	154
12th layer	12	13	156
Total number of cells			1,300

Dimensions.—Each cell had a side of 25 centimeters, so that the roof, or ridge-pole, measured 6 meters, extending laterally across the top of the structure. The oblique sides were 3 meters in length, and the bottom, or floor, formed a square having a side of 3 meters. The whole structure constituted a section of a tetrahedral kite—the upper half, in fact, of a kite having the form of a regular tetrahedron with a side of 6 meters.

Weight.—The winged cells composing this structure weighed on the average 13.84 gms. apiece, so that the whole cellular part of the structure which supported all the rest, consisting of 1,300 winged cells, weighed 17,992 gms.

In addition to this, the kite carried as dead load stout sticks of wood, which were run through the structure to distribute the strain of the pull upon the strong parts of the framework—that is, upon the junction points of the cells. The outside edge of the kite was also protected by a beading of wood. The whole strengthening material weighed 9,702 gms., and the kite as a whole weighed 27,694 gms. (61 lbs.).

Surface.—I estimate the surface of an equilateral triangle having a side of 25 centimeters as about 270.75 square centimeters; in which case the silk surface of a single winged cell consisting of two triangles amounts to 541.5 square centimeters, and the actual silk surface employed in 1,300 cells equals 70.3950 square meters (757.7 sq. ft.).

The surfaces are all oblique, and if we resolve the oblique surfaces into horizontal and vertical equivalents (supporting surfaces and steadying surfaces) we find that the resolved horizontal equivalent (supporting surface) of a single winged cell forms a square of which the diagonal measures 25 centimeters, and this is equivalent to a rectangular parallelogram of 25 x 12.5 centimeters, having an area of 312.5 square centimeters.

Thus an actual silk surface of 541.5 square centimeters arranged as the two wings of a winged cell yields a supporting surface of 312.5 square centimeters.

In kites, therefore, composed exclusively of tetrahedral winged cells each having a side of 25 centimeters, the area of supporting surface bears the same proportion to the actual surface as the numbers 3,125 to 5,415; or 1 to 1.7328.

$$\frac{\text{Supporting surface}}{\text{Actual surface}} = \frac{1}{1.7328}$$

A simple way of calculating the amount of supporting surface in such structures is to remember that there are 32 cells to the square meter of supporting surface; therefore the 1,300 cells of the kite "Frost King" had a supporting surface of 40.6250 square meters (437.3 sq. ft.).

Ratio of Weight to Surface.—The actual silk surface employed in the "Frost King" was 70.3950 square meters (757.7 sq. ft.), the weight of the kite was 27,694 gms. (61 lbs) ; so that on the basis of the actual surface, the flying weight was 393.4 gms. per square meter (0.08 lbs. per sq. ft.).

But, for the purpose of comparing the flying weight of a tetrahedral kite with that of other kites, in which it is usual to estimate only the aëroplane surfaces that are substantially in a horizontal plane, it would be well to consider the ratio of weight to horizontal or supporting surface in this kite.

The weight was 27,694 gms. (61 lbs.), the resolved horizontal or supporting surface was equivalent to 40.6250 square meters (437.3 sq. ft.), and the flying weight for comparison with other kites was 681.7 gms. per square meter of supporting surface (0.14 lbs. per sq. ft.).

The kite, in addition to its own weight, carried up a mass of dangling ropes and a rope-ladder, as well as two flying cords of manilla rope. The impedimenta of this kind weighed 28,148 gms. (62 lbs.). It also supported a man, Mr Neil McDermid, who hung on to the main flying rope at such a distance from the cleat attached to the ground that when the rope straightened under the strain of the kite he was carried up into the air to a height of about 10 meters (over 30 ft.). The weight of this man was 74,910 gms. (about 165 lbs.). Thus the total load carried by the kite, exclusive of its own weight, was 103,058 gms. (or 227 lbs.).

The whole kite, load and all, including the man, therefore, weighed 130,752 gms. (288 lbs.), and its flying weight was 1,857.4 gms. per square meter of actual surface (0.38 lbs. per sq. ft.), or 3,218.5 gms. per square meter of supporting surface (0.66 lbs. per sq. ft.).

A. G. B.

APPENDIX B

Partial Bibliography Relating to Aerial Locomotion, Prepared, through the Courtesy of the Smithsonian Institution, by Dr Cyrus Adler, Assistant Secretary, in Charge of Library and Exchanges.

Dr Adler says:

"In accordance with your request, I am authorized to send you herewith a list of the writings of S. P. Langley, Octave Chanute, Otto Lilienthal, Lawrence Hargrave, and A. M. Herring, to be used in connection with your recent paper on aerial locomotion. I ought to explain that, excepting in the case of Mr Langley's writings, I am not at all sure that the lists are complete, since the time afforded for bringing together the references was very short, and of course there may be publications in out-of-the-way journals which would only be revealed by a more extended inquiry. I have also appended a list of papers on the subject published by the Smithsonian Institution, as the Smithsonian publications are accessible in all libraries throughout the country, whereas many of the publications cited in the other lists are not readily to be found."

S. P. LANGLEY

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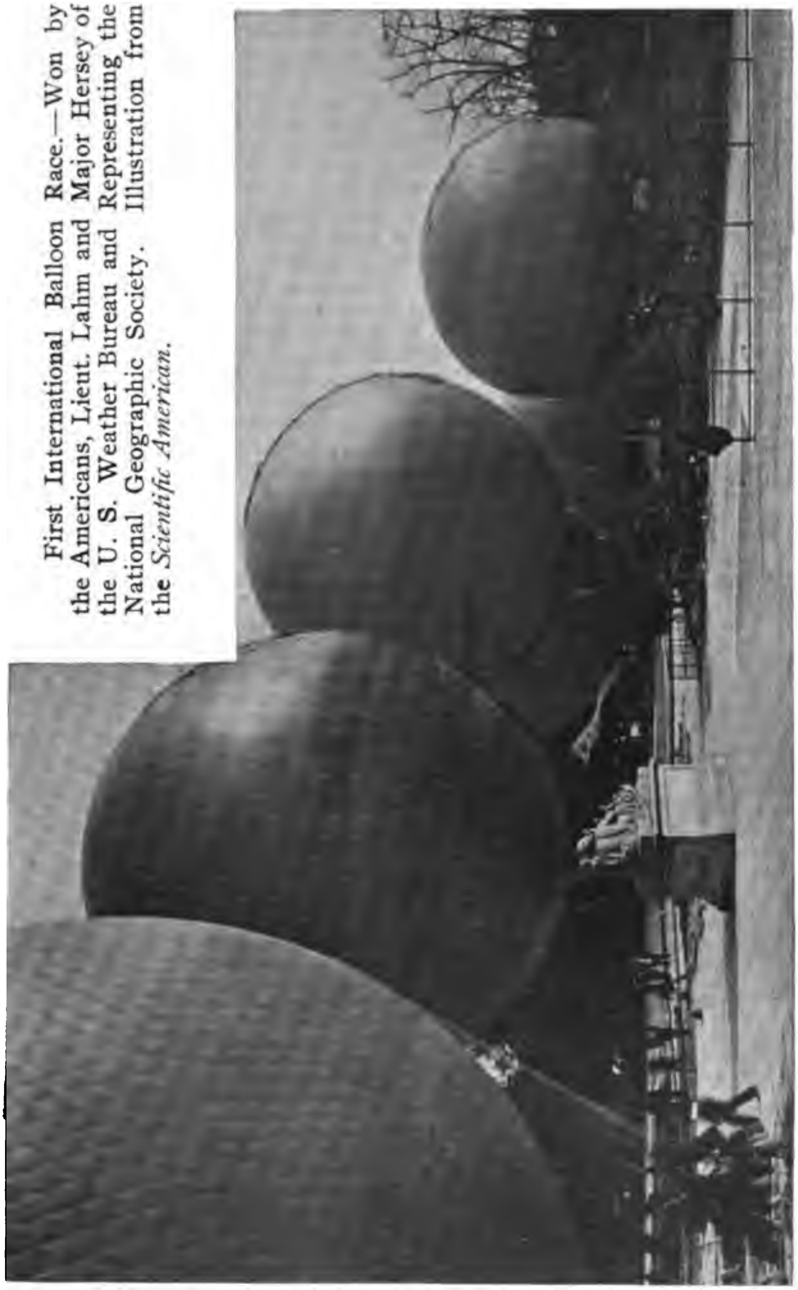
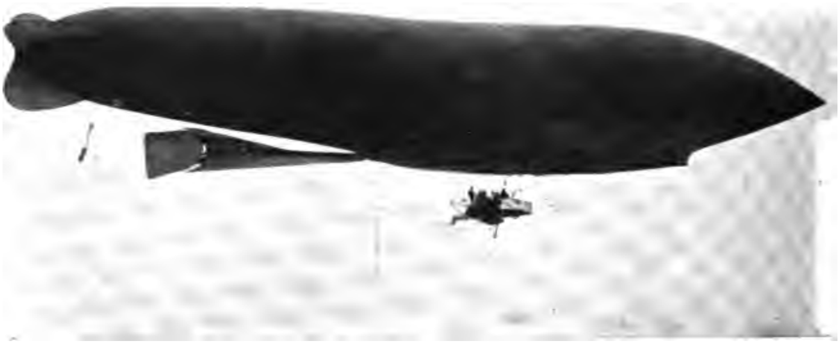
(*Continued on page 33*)



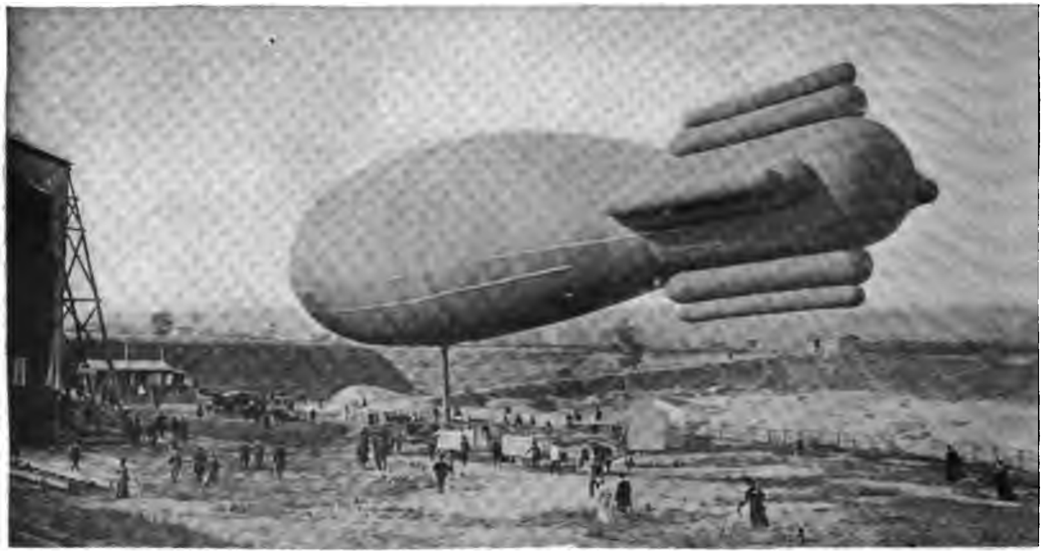
First International Balloon Race.—Won by the Americans, Lieut. Lahm and Major Hersey of the U. S. Weather Bureau and Representing the National Geographic Society. Illustration from the *Scientific American.*

Some of the Balloons Which Took Part in the Great Race for the Gordon Bennett Cup



The French Military Dirigible, "Patrie," in Flight

The latest French airship, "La Patrie," is 33¾ feet in diameter by 196 feet long, and has a capacity of 111,195 cubic feet. Driven by a 70-horsepower motor and two propellors, this dirigible has recently made about 30 miles an hour. Its lifting capacity is 2,777 pounds. Illustration from the *Scientific American*

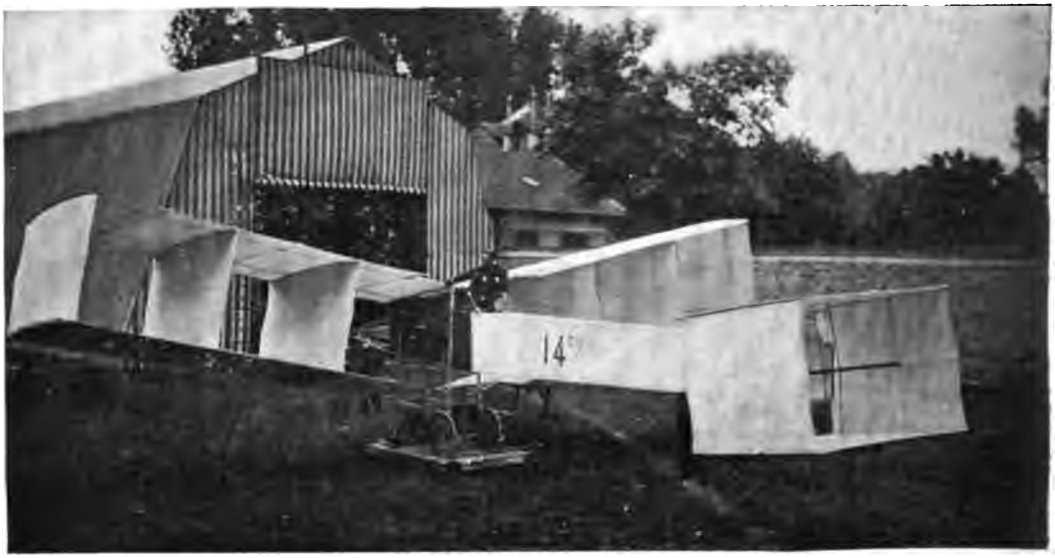


The New Deutsch Airship "Ville de Paris," the Latest and Largest Dirigible Balloon

The peculiar arrangement of twin, hydrogen-filled cylinders forms a sort of balancing tail. This airship has a length of 60 meters (196.85 feet) and a diameter of 10.8 meters (35 43 feet, while its capacity is 3,000 cubic meters (105,943 cubic feet). Its propellers are placed on either side of the body framework or "nacelle," and at about the center of the latter, which is boat-shaped. The weight which can be carried, outside of the equipment and the fuel sufficient for a ten hours' run, is about 1,100 pounds. A 70-horsepower Panhard motor is used. Illustration from the *Scientific American*

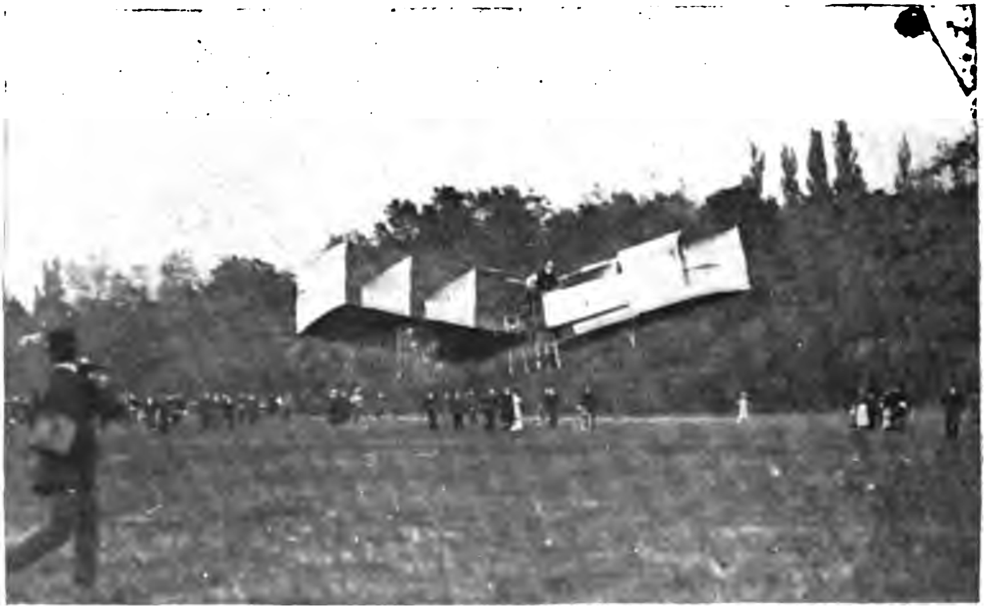
Count Von Zeppelin's Airship—the Largest and Fastest Thus Far Constructed—Coming Out of Its Shed and Performing Various Evolutions Above Lake Constance

This airship, which is 38 feet in diameter by 410 feet in length and which has a capacity of 367,120 cubic feet, held itself stationary against a 33½-mile-an-hour wind on January last, by means of two 35-horsepower gasoline motors driving four propellers. The airship can lift three tons additional to its own weight, which gives it a radius of 3,000 miles at 31 miles an hour. On October 11, 1906, Count Zeppelin maneuvered this dirigible balloon above Lake Geneva, ascending to a height of 2,500 feet and steering the huge cigar-shaped aërostat very nicely. The airship is mounted on floats, so that it works equally well on the water. During one flight it remained in the air an hour and twenty minutes, although the steering-gear was caught in the skeleton framework and became partly unmanageable. The attempts proved also that the airship was dirigible in spite of its great size, as several complete circles were made while in the air. Illustrations from the *Scientific American*



Santos-Dumont's Aëroplane

The inventor is seated on top of the basket, just ahead of the motor



The Aëroplane making its First Successful Free Flight with its Owner in Control

The machine flew about 200 feet at an elevation of 10 feet from the ground
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